Year: 2015

Soil variability in mountain areas

Zanini, Ermanno ; Freppaz, Michele ; Stanchi, Silvia ; Bonifacio, Eleonora ; Egli, Markus

Abstract: The high spatial variability of soils is a relevant issue at local and global scales, and determines the complexity of soil ecosystem functions and services. This variability derives from strong dependencies of soil ecosystems on parent materials, climate, relief and biosphere, including human impact. Although present in all environments, the interactions of soils with these forming factors are particularly striking in mountain areas.

Originally published at:
Zanini, Ermanno; Freppaz, Michele; Stanchi, Silvia; Bonifacio, Eleonora; Egli, Markus (2015). Soil variability in mountain areas. In: Romeo, R; Vita, A; Manuelli, S; Zanini, E; Freppaz, Michele; Stanchi, Silvia. Understanding Mountain Soils: A Contribution from mountain areas to the International Year of Soils 2015. Rome: FAO, 60-62.

Ermanno Zanini, Michele Freppaz, Silvia Stanchi, Eleonora Bonifacio and Markus Egli

Soil variability in mountain areas

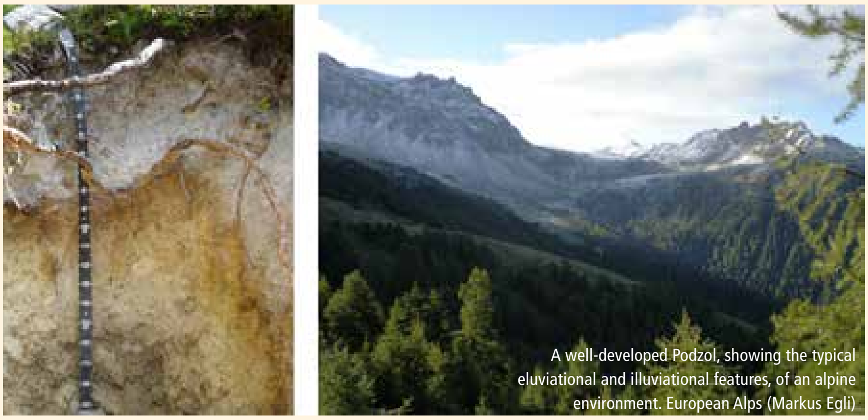
Farmers tilling soil for crops aiding post-conflict districts so they can begin growing crops again. Kirimetiyawa, Sri Lanka (@FAO/Ishara Kodikara)

The high spatial variability of soils is a relevant issue at local and global scales, and determines the complexity of soil ecosystem functions and services. This variability derives from strong dependencies of soil ecosystems on parent materials, climate, relief and biosphere, including human impact. Although present in all environments, the interactions of soils with these forming factors are particularly striking in mountain areas.

Principle patterns of soil distribution can be found in the work of natural scientists across the decades. Writing in 1899, Dokuchaev mentioned that spatial changes in moisture and temperature conditions (*i.e.* in climate) determine soil properties. This gave rise to the Laws of Horizontal Soil Zonality (for plain regions) and Vertical Soil Zonality (for mountain regions).

In mountain areas, altitude and relief strongly affect the soil's energy balance and, as a consequence, the soil temperature. These two variables influence snow cover duration and the amount of precipitation, which can for example differ between windward and leeward sites. The thermal conditions and availability of water in soils are the main drivers of chemical and physical weathering. The relief has additional impact due to geological uplift, the differing hardness of parent material and its resistance to erosion and weathering. Vegetation is linked to the prevailing climatic conditions, but also to the parent material as its composition determines which plant species can grow and, thus, indirectly influences soil development.

At alpine sites, the bare surfaces left by retreating glaciers offer the opportunity to observe early stages of soil development, which validates existing theories about ecosystem evolution and makes it possible to determine the speed of soil-forming processes. On silicatic parent material, chemical weathering, acidification and soil formation proceed very fast in mountainous areas due to the often relatively young surfaces and the availability of fresh mineral surfaces. With surface age, these rates usually decrease. In some cases, aeolian deposits may also be an important soil-forming factor in mountainous and alpine soil pedogenesis. In addition, wind-blown materials, such as carbonates, may contribute to reducing the acidity of soils.



A well-developed Podzol, showing the typical eluviational and illuviational features, of an alpine environment. European Alps (Markus Egli)

Often, soil morphology and properties cannot be related to surface age directly, because soils may exhibit progressive and regressive evolutional stages. At geomorphologically active sites, where erosion or accumulation are under way, soils are often polygenetic. Mountain soil development is often characterized by the redistribution of soil material along the slopes.

Soil can only persist at a given location if erosion does not remove it faster than it can be produced. Erosion leads to a rejuvenation of the soils and increases their weathering rates. This means that, to a certain extent, erosion and chemical weathering rates are positively correlated. Larsen *et al.* showed that, under undisturbed conditions, soil production enables even rapidly eroding landscapes to retain a cloak of soil. However, a delicate balance exists between soil production and erosion that may become very intense and endanger the persistence of fertile soil.

A Vertisol from the Iblei mountains in a Mediterranean environment. Sicily, Italy (Markus Egli)

Mountain soils are highly dynamic and sensitive systems that react to environmental changes such as climate change and intense land use. Human-induced erosion rates are, in some mountain areas, much beyond (maximum) soil production rates. Extensive erosion rates lead to rapid soil degradation and loss of areas for plant growth which, in turn, also negatively affects carbon sequestration.

The environmental and site variables have considerable effects on pedogenesis, organic matter input and its turnover, leading to soils that under undisturbed conditions are thick and anisotropic, and develop clearly distinct horizons. For example, at cooler sites or at sites with ample water (having anoxic conditions), the decomposition of organic materials may be hindered. As a consequence, the rate of biomass production is often greater than the rate of decomposition (plant and soil respiration). This results in a net accumulation of plant and animal remains which eventually causes paludification (*i.e.* waterlogging of terrestrial soils by organic materials) with the formation of histosols, which are characterized by thick organic horizons.

In cold areas dominated by siliceous rocks, on slopes with conifers or in the alpine dwarf-shrub zone, Podzols are quite widespread. Leptosols dominate at higher elevations in the alpine tundra while, at lower elevations, they only occur at geomorphically active sites (*e.g.* shallow landslides, snow avalanches) where erosion/accumulation and other disturbances inhibit further evolution. In these areas, buried soils, often truncated by erosion, are frequently overlain by younger soils developing on colluvium, debris flows and detrital slope deposits.

A soil (Calcisol) of an aridic mountain environment shwoing a substantial accumulation of secondary carbonates. Wind River Range, Wyoming, United States (Markus Egli)

The "catena" (chain) approach is a useful tool to detect common rules of soil development even in such diverse environments. The rugged and abruptly changing topography affects soil evolution in multiple ways, including the redistribution of the soil material along the slopes to valley floors. The exposure, for example, may have a tremendous effect on chemical weathering: north-facing slopes are often characterized by a higher element of leaching and consequently a higher weathering degree than south-facing slopes at the same elevation. At high altitudes, exposure and relief influence prevailing winds or snow distribution. This is the base concept of the "synthetic alpine slope model", which suggests that soil development across an alpine slope is at least partially governed by the number of snow-free days per year which, in turn, affects soil temperature and moisture.

Although research at the regional level is needed, theories and experiences from elsewhere can greatly reduce efforts, as can modelling. However, transferring models and technology to field conditions can present serious difficulties, particularly in heterogeneous environments, and the effect of scale emerges as one of the main problems. Soil variability also means pedodiversity which is part of local and cultural heritage. This heritage includes the human impact which has widely and dramatically changed the soil cover. Now, with the knowledge of the origin, the significance and degree of soil variations in space and time, pedologists can contribute to support conservation of soil as a primary and nearly non-renewable resource. Because mountainous soils developed in a strongly dynamic landscape, are highly variable and react very sensitively to environmental change, they deserve particular protection.